A REPLACEMENT OF WOOD BY DOLOMITE

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A score or more minerals are known to have replaced wood. Cases of most of these types of replacement were recorded by J. R. Blum[1] during the years 1847–79. Since 1879 there have been few additions to the list of wood-replacing minerals as given by Blum. To my knowledge, replacement by dolomite has not before been mentioned. For this reason, the accompanying account has been made as complete as possible.

In the known replacements of wood chalcedony is undoubtedly the most universal petrifying mineral. Fine examples of this kind of replacement are found in the petrified forests of Arizona, where very large tree trunks have been completely agatized.[2] Petrifactions of this type come from localities in Colorado, Utah, California, and from the Yellowstone Park. I have at hand an unlabeled specimen of petrified wood which is thought to come from Arizona, in which the wood is largely replaced by quartz. A thin section of this specimen shows anhedral quartz crystals which include sometimes a dozen well-outlined wood cells. The general character of the quartz is similar to that to be described on a later page. Wood opal replacing entire tree trunks is found in Hungary; nor is it uncommon in this and other countries. Precious opal, usually as a late development after common wood opal, is known to come from Australia and from a deposit in Nevada, where the opal is being recovered for commercial purposes. Blum mentions opalized wood with an incrustation of hyalite.

Replacements by calcite and aragonite have been recognized in many places. The strong crystallization of these two minerals

[1] J. R. Blum, *Pseudomorphosen des Mineralreichs*, Nachträge, 1, 2, 3, 4.

[2] G. P. Merrill, "The Fossil Forest of Arizona," *Am. Mus. Jour.*, Vol. XIII, pp. 311–16.

usually obliterates the cell structure of the wood. An interesting case in which the wood tissue is well preserved by calcite has recently been described by C. W. Greenland.[1] Fragments of wood and plant remains petrified by pyrite, and marcasite are recorded from carbonaceous formations of many districts. Blum describes replacements of wood by barite, from the Lias chalk beds of central Germany; by cinnabar, from Bavaria; by fluorite, from Saxony; by sulphur, from Italy; and by malachite and azurite, from the Urals and West Africa. The same author also records replacements of wood or plant remains by gypsum, phosphorite,[2] hematite, limonite, siderite, sphalerite, galena, chalcopyrite, and chalcocite. He mentions a case in which wood tissue is well preserved by a kaolin-like substance most closely resembling halloysite. Blum also discusses replacements of wood, from near Moutiers in the French Alps, by a mineral closely resembling talc, and compares this mineral with some pyrophyllite from the Thuringen district in Germany. The pyrophyllite, however, is not described as replacing wood. Grabau[3] mentions chlorite as replacing plant remains.

In an article on the "Red Bed" type of copper ores, Rogers[4] lists as occurring in petrified wood: hematite, pyrite, bornite, chalcocite, chalcopyrite, covellite, melaconite, limonite, malachite, azurite, and quartz. Of these, only hematite and pyrite are considered as directly replacing wood.

The dolomitized wood herein described belongs to the mineral collections of Professor A. F. Rogers, of Stanford University, to whom I am indebted for the privilege of describing it as well as for suggestions as to the description itself. The specimen was found in 1916 in the Midway Oil Field, Kern County, California, by C. R. Swartz. It comes from what is locally known as the McKittrick formation, which may include sediments of upper Miocene, Pliocene, and Pleistocene age.[5]

[1] C. W. Greenland, *Econ. Geol.*, Vol. XIII, pp. 116–19.

[2] Probably impure collophane.

[3] A. W. Grabau, *Principles of Stratigraphy*. A. G. Seiler & Co., 1913.

[4] A. F. Rogers, *Econ. Geol.*, Vol. XI, pp. 366–80.

[5] Arnold and Johnson, *U.S.G.S. Bull. 406*.

The hand specimen measures four by three by two inches (Fig. 1). Worn and rounded corners indicate that it is float, for which reason the horizon from which it came cannot be more definitely established. The specimen is of two distinct colors, a buff outer part which may correspond to sapwood, and a dark-gray inner part which may have been heartwood. The former is dolomite, the latter silica. Qualitative analysis of the dolomite gave roughly half as much magnesium as calcium and an appreciable, though not large, amount of iron. The general buff color throughout the dolomite is due as much to the oxidation of this iron as to organic matter. Both Professor D. H. Campbell and Professor Leroy Abrams, of Stanford University, have determined the wood as that of gymnosperm and almost assuredly coniferous. Due to the imperfect preservation of fiber, further identification was not made.

FIG. 1.—Wood replaced by dolomite. Gray part is compact dolomite showing radial lines and small black siliceous dots, which may represent location of resin ducts. In center of specimen is coarser dolomite in rhombs and compound groups. Black portion, showing annual rings, is quartz. (Slightly reduced.)

In the center of the specimen is a spot of darker brown color containing rather coarse dolomite crystals. In this place a feature which has been described by E. T. Wherry[1] (in an account of a petrifaction by calcite from Yellowstone National Park) is rather prominent, e.g., the individual or compound convex-bordered crystals in a siliceous matrix. On either side of the central darker area is the buff mass of dolomite replacing the outer portion of the

[1] E. T. Wherry, *Proc. U.S. Nat. Museum*, Vol. LIII, pp. 227–30.

specimen. The most noticeable feature in this part is the parallel radial lines of buff dolomite. Adjoining lines usually are separated by fine brownish black silica.

Small dolomite crystals grouped radially about a center of silica also can be seen in this part of the specimen. These groups are made prominent in the hand specimen by the black silica cores. They occur with apparent regularity throughout the dolomite, and

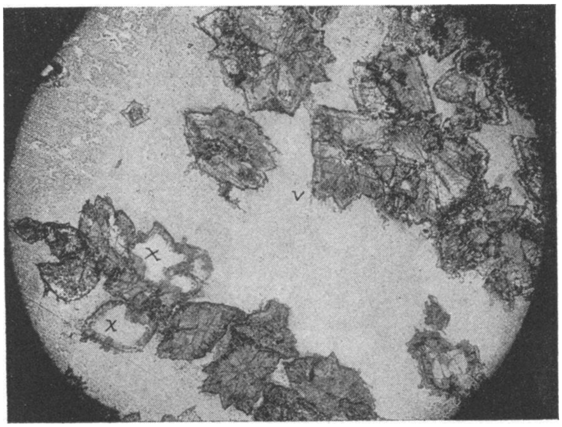

FIG. 2.—Thin section showing compound dolomite crystals in siliceous matrix. Replacement of dolomite by silica is illustrated around places marked "*x*." White central part (at "*x*") is a hole in the slide where the dolomite has pitted out. The fringe around the hole is silica, surrounded by the darker organic matter excluded by the dolomite during growth. This same effect can be seen around most of the rhombs. This section also shows second generation dolomite developing along the edges of the older rhombs as at "*v*." $\times 9\frac{1}{2}$.

it was at first suggested by Professor Abrams that they might mark the location of resin ducts. This seems doubtful unless the outer part of the specimen is a petrifaction of bark. However, recognition of wood structure throughout the dolomite is at best largely a guess.

Annual rings are not well preserved in the dolomite. In the dark-gray siliceous part of the specimen, however, annual rings are prominent. They are marked by the gradual darkening of color from spring growth to winter. In one or two places there are

cavities with inwardly projecting quartz crystals. Small euhedral quartz crystals have developed on the outside of the siliceous portion of the material.

Under the microscope the individual dolomite crystals are first to attract attention (Fig. 2). The well-developed rhombs usually average about one millimeter on the long diagonal. The dominant form is the unit rhombohedron $r(10\bar{1}1)$, sometimes modified by

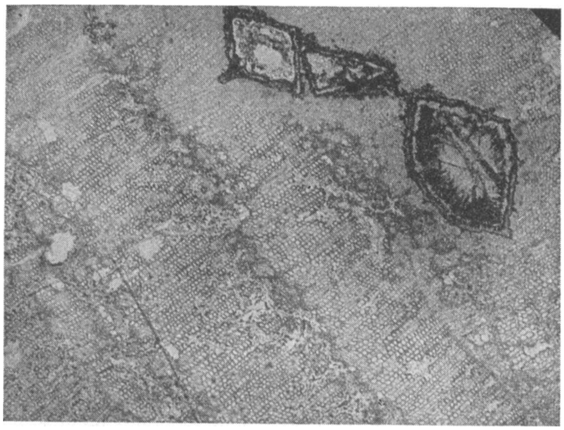

FIG. 3.—Thin section of corroded dolomite rhomb in quartz ground-mass. Also showing patchy retention of cell outlines, especially along annual rings. Notice apparent distortion of cells bordering the larger dolomite rhomb. $\times 21\frac{3}{4}$.

$e(01\bar{1}2)$. These crystals neither include nor preserve any cell outlines. A dark-brown rim around the edges indicates that they have excluded the woody material. Replacement of the crystals along borders by finely crystalline silica leaves a corroded dolomite core surrounded at a little distance by a brown organic halo, as the development of the silica does not affect the position of the organic matter (Fig. 3). In a few cases, surrounding groups of cells seem to have been squeezed by the growth of the rhombs. Cells are usually misshapen near the annual rings. However, one or two occurrences can be seen in which cells, bordering dolomite crystals which lie entirely within the customarily well-developed spring growth, are distorted as if by pressure from the crystal (Fig. 4). This is an indication of the formation of the

dolomite before the surrounding silification. In general, cell outlines are not evident near the borders of dolomite rhombs. Had the dolomite been a replacement of silica, one would expect to find the cell outlines in the silica as well preserved in the immediate neighborhood of the rhombs as elsewhere. The exclusion of woody material is also evidence of the early crystallization of this dolomite.

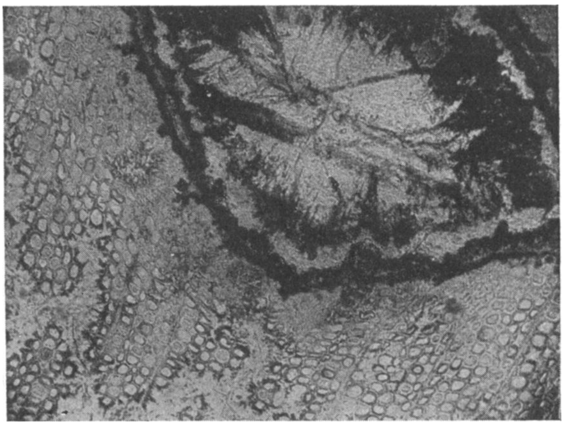

FIG. 4.—High power view of rhomb in Figure 3, showing dolomite core, organic rim, and silica fringe separating the two. Also shows distorted cells. $\times 76\frac{2}{3}$.

In the main mass of buff dolomite the crystals are slightly smaller than the rhombs just mentioned, and they rarely show crystal outlines. With magnification the thin section appears to be a compact mass of rather even fine-grained crystals, usually about twice as long as wide. Many crystals appear to be twinned. No polysynthetic twinning was noticed either in the thin section or in fragments. An approach to cyclic twinning is occasionally seen, but commonly the apparent twinning is of a simple contact nature. However, the presence of twinned crystals was not proved.

The dolomite crystals are sometimes arranged side by side in long rows; opposite them is a similar row; and along the center where the rows touch are two imperfect chains of distorted cell outlines. The rows are always arranged radially with respect

to the replaced wood as a whole. Although these "chains of cells" include varied sizes and odd shapes, it is safe to say that they are a relic of the original vegetable fiber. The size of the cells in these chains varies from 0.02 mm. to 0.07 mm. in diameter and averages 0.04 mm., which is a range in size and an average also true of cell outlines well preserved by silica. Occasional cells are replaced by individual dolomite crystals which do not extend beyond the cell walls, and still other cells show evidence of secondary enlargement of dolomite, proceeding outward from the cell as center. Cell outlines in dolomite are not often retained except in or near the cell chains. The parallel row arrangement is repeated throughout much of some of the thin sections. It is this arrangement which causes the radial lines of buff and black as seen in the hand specimen. The fine black lines are composed of a late silica which develops most readily between the abutting ends of the dolomite crystals. An explanation for this phenomenon which seems tenable is that the dolomite started crystallization simultaneously along somewhat widely spaced radial lines; that in the first crystallization some of the cell outlines were preserved; but that in the subsequent growth wood structure was largely obliterated. Judging from the secondary enlargement of dolomite with a cell as a center, the initial crystallization occurred within the cell, in some cases at least.

Often the dolomite crystals are grouped radially with a small center of finely crystalline silica of the same late type as just mentioned. The silica, of course, is a development subsequent to the radial growth of the dolomite. The siliceous cores of these groups are seen as fine black dots in the hand specimen. Extinction in sequence often occurs in the radially grouped dolomite, and when combined with simultaneous extinction in opposite sectors, gives the group a rough spherulitic appearance.

Thin sections of what has been called the heartwood show the best retention of cell structure and annular rings. For the most part, the replacing mineral is quartz.[1] Crystals are usually

[1] The exact relations of quartz, chalcedony, fibrous, and other forms of silica have not been settled. In this article the identification of quartz as such is made easy by its occasional euhedral form. The chalcedony to be mentioned later was so called on account of its lesser refractive index than quartz and negative elongation.

anhedral and of a fairly uniform size in any one part of the thin section, although the average size for the different parts of the specimen may vary from very small to a maximum width of about 0.2 mm. In general, it is the rule for one quartz crystal to contain several wood-cell outlines. As before stated the average diameter of cells is 0.4 mm., with a range of from 0.02 mm. to 0.07 mm. In longitudinal sections the quartz is usually elongated in the direction of the wood fiber, showing that the growth of crystals has been influenced by cell structure. Distinct crystal outlines with an occasional hexagonal cross-section are noticeable in several places throughout the anhedral quartz. They are better-developed individuals belonging to the same silification. As may be seen in one of the accompanying photographs (Fig. 3), retention of cell structure is patchy. The best-developed quartz crystals occur on the borders of those places in which no cell structure is evident. They give the appearance of having grown into an open space, or at least into a decayed spot, where there was nothing to resist their assuming idiomorphic form. At their roots these crystals also inclose cell outlines.

Secondary enlargement of the euhedral and subhedral crystals is seen in several places. A rough radial grouping occurs in some of the quartz. Extinction in sequence often gives these groups the same coarsely spherulitic appearance as in the dolomite. Wavy extinction is common in many crystals. In one thin section cell outlines are well preserved by another form of silica. This silica is very fine grained, fibrous, often spherulitic, with very weak double refraction, about the same index of refraction as quartz, and of negative elongation.

Late silica and dolomite are found in veinlets and cavities. In several small veinlets which cut both siliceous ground-mass and early dolomite crystals, banding by alternating quartz and dolomite occurs. Dolomite also is found in patches throughout the quartz replacement of heartwood. In cavities it is often in the center as a filling around projecting euhedral quartz crystals. A very prominent occurrence of this late dolomite is as an enlargement, although not in crystallographic orientation, of the older rhombs and dolomite crystals.

The later silification develops with this dolomite as a replacement of the previously formed quartz and dolomite as a cavity and vein filling, and as an incrustation. That it actually replaces the earlier quartz is not certain, but its replacement of dolomite is manifest in the corroded rhombs separated from their excluded organic halo by silica. Chalcedony and quartz occur in this silification. Quartz predominates. It occurs in subhedral crystals in veinlets, presenting a microscopic comb structure, or as cavity filling, in which case it has developed from the walls inwardly as in a geode. In both of these cases it often shows zonal lines. It replaces the dolomite around the borders, and, especially in the case of the compound dolomite groups, it begins replacing in the center of the group as well as along the edges. The development between parallel rows of dolomite crystals has already been mentioned. The chalcedony and fibrous silica are found in the centers of filled cavities, in veinlets, and as a replacement of dolomite.

Another very interesting late development is that of minute patches of an opaque gray metallic mineral, taken to be hematite, but in too minute amounts to test. This appears in a polished surface in veinlets and patches and in one case in a small rhomb as if it were a pseudomorph after dolomite.

In conclusion: dolomite seems to be the earliest replacing mineral. The small area of large-sized rhombs is taken to be the result of replacement in a partially rotten or injured spot in the wood. The outer part of the specimen was replaced by a finer-grained dolomite, but without retention of much of the cell structure. The curious arrangement of crystals in rows points to initial crystallization along radial channels. What furnished these channels is not clear. The distance between rows is greater than the spaces between medullary rays. Also, the channels have longitudinal extent, which leads to the possible hypothesis that they were caused by closely spaced radial cracks.

From the general character of the petrification it appears that crystallization took place rather slowly along certain lines, later spreading throughout the wood and destroying most of the cell outlines. For some reason these solutions gave out before complete dolomitization, for the inner part of the specimen shows no evidence

of having been attacked by dolomite. Blum describes a petrifaction by opal in which the outer part is opal, whereas the core is unaltered wood, showing that replacement progressed from the outside toward the center. It may be that in the case in hand petrifaction occurred while at least a complete cross-sectional fragment of the wood was intact, and that dolomitization started from the outside and developed inwardly. The solutions containing the carbonate then gave place to others with silicic acid which permeated the heartwood and caused its silification. Cavity and crack fillings, and rearrangements, followed at some time later.